U. S. DEPARTMENT OF THE INTERIOR

U. S. GEOLOGICAL SURVEY

REVISED PRELIMINARY GEOLOGIC MAP OF THE NEW CASTLE QUADRANGLE, GARFIELD COUNTY, COLORADO

by

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DESCRIPTION OF MAP UNITS

[Surficial deposits shown on the map are estimated to be at least 1 m thick. Fractional map symbols (for example, Qlo/Qto) are used where loess mantles older surficial deposits and the underlying deposits have been identified. Thin, discontinuous colluvial deposits, residual material on bedrock, small artificial fills, and small talus deposits in the valleys of Elk Creek and Main Elk Creek were not mapped. Areas underlain by the Wasatch Formation (Tw), Mesaverde Group (Kmv), Maroon Formation (Phm), Mancos Shale (Km), and Eagle Valley Formation (Phev) commonly have unmapped colluvial deposits especially in area of forest vegetation or dense oak brush. Also not mapped are several elongate areas above mined coal beds on the north side of the Grand Hogback, near Burning Mountain and Coal Ridge, where the ground surface is highly oxidized, fractured, and prone to subsidence (Stover and Soule, 1985). Divisions of Pleistocene time correspond to those of Richmond and Fullerton (1986). Age assignments for surficial deposits are based chiefly on the degree of modification of original surface morphology, height above stream level, and degree of soil development. Age assignments for units Qtt, Qbb, QTba, and Tg are based chiefly on two regional rates of stream incision of about 0.14 m/ k.y. (k.y., thousand years) and 0.16 m/k.y. and on a regional rate of tectonic uplift of about 0.18 m/k.y. The first incision rate is based on an average of three values for stream incision since the deposition of the 620-ka (ka, thousand year old) Lava Creek B volcanic ash: (1) about 90 m along the Colorado River near the east end of Glenwood Canyon (Izett and Wilcox, 1982), (2) about 88 m along the Roaring Fork River near Carbondale, Colorado (Piety, 1981), and (3) about 80-85 m along the White River near Meeker, Colorado (J.W. Whitney, oral commun., 1992; Whitney and others, 1983). The second incision rate, possibly a minimum rate, is based on about 1,600 m of downcutting by the Colorado River since the eruption of the about 10 Ma (Ma, million year old) basalt on Grand Mesa (Marvin and others, 1966) near Palisade, Colorado, about 70 km southwest of the map area. The rate of tectonic uplift of about 0.18 m/10 k.y. was determined for the Derby Peak fauna in the Flat Tops area (Colman, 1985), which is about 50 km east-northeast of the map area. Tentative correlations of units Qfp, Qty, Qto, and Qtt with other alluvial units is based chiefly on the height of the alluvial unit above stream level and the geomorphic relations of the alluvial unit to moraines of known or inferred age. Soil-horizon designations are those of the Soil Survey Staff (1975), Guthrie and Whitty (1982), and Birkeland (1984). Most of the surficial deposits are calcareous and contain different amounts of primary and secondary calcium carbonate; stages of secondary calcium carbonate morphology (refered to as stages I through IV Bk or K horizons in this report) are those of Gile and others (1966). Grain sizes given for surficial deposits and bedrock are based on field estimates and follow the modified Wentworth scale (American Geological Institute, 1982). In descriptions of surficial map units, the term “clasts” refers to the fraction greater than 2 mm in diameter, whereas the term “matrix” refers to the particles less than 2 mm in size. Dry matrix colors of the surficial deposits were determined by comparison with Munsell Soil Color Charts (Munsell Color, 1973). The colors of the surficial deposits correspond to those of the sediments and(or) bedrock from which they were derived. Surficial deposits derived from non-red sediments and bedrock commonly range from pale yellow (2.5Y 7/4) to light brown (7.5YR 6/4). Those derived from red sediments and bedrock commonly range from light reddish brown (5YR 6/4) to red (2.5YR 5/6). Bedrock colors were determined by comparison with the Geological Society of America Rock-Color Chart (Rock-Color Chart Committee, 1951). Hyperconcentrated-flow deposits mentioned in this report are deposits that are intermediate in character between stream flow and debris-flow deposits. In this report, the term “colluvium” includes mass-wasting (gravity-driven) deposits as well as sheetwash deposits. As used in this report the term “hydrocompaction” refers to any water-induced decrease in volume observed or detected at or near the ground surface that is produced by a decrease in void space resulting from a more compact arrangement of particles and (or) the dissolution and collapse of rock fragments or matrix material. The term “expansive soils” includes both pedogenic soil and surficial deposits that expand when wet and shrink when dry. A previous Open-File Report of this map was published recently (Green and others, 1993); however, incorrect location of bedrock stratigraphic contacts, incomplete subdivision of mappable units in bedrock, incorrect location and identification of faults and folds in bedrock, and lack of drill hole information on that report has made this revision necessary. Metric units are used in this report (except where the nominal total depth of drill holes is reported on the map in feet from drilling records). A conversion table is provided for those more familiar with English units (Table 1). A review of the divisions of geologic time used in this report is also provided (Table 2)]

Table 1. Factors for conversion of metric units to English units to two significant figures

Multiply	By	To obtain
centimeters (cm)	0.39	inches
meters (m)	3.3	feet
kilometers (km)	0.62	miles
kilograms per cubic meter (kg/m^3)	0.062	pounds per cubic foot

Table 2. Definitions of divisions of geologic time used in this report

ERA	Period	Epoch	Age (years)
CENOZOIC	*Quaternary*	*Holocene*	*0 to 10 thousand*
		Pleistocene	*10 thousand to 1.65 million**
	Tertiary	*Pliocene*	*1.65 to 5 million*
		Miocene	*5 to 24 million*
		Oligocene	*24 to 38 million*
		Eocene	*38 to 55 million*
		Paleocene	*55 to 66 million*
MESOZOIC	*Cretaceous*		*66 to 138 million*
	Jurassic		*138 to 205 million*
	Triassic		*205 to 240 million*
PALEOZOIC	*Permian*		*240 to 290 million*
	Pennsylvanian		*290 to 330 million*

After Hansen (1991); *exception: 1.65 million from Richmond and Fullerton (1986).

ARTIFICIAL-FILL DEPOSITS—Compacted material composed mostly of silt, sand, and rock fragments placed beneath highways and drilling platforms and in mine dumps

af **Artificial fill (latest Holocene)**—Compacted and uncompacted fill material composed mostly of silt, sand, and rock fragments. Mapped beneath segments of Interstate 70 and the nearby tracks of the Denver and Rio Grande Western Railroad, beneath drilling platforms, and in coal mine dumps. Thickness generally less than 10 m thick

ALLUVIAL DEPOSITS-Silt, sand, and gravel in flood plains, stream channels, and terraces along the Colorado River and its major tributaries

Qfp **Flood plain and stream channel deposits (Holocene and late Pleistocene)**—Chiefly clast-supported, slightly bouldery, pebble- and cobble-gravel in a sand matrix that is locally overlain by gravelly sand to sandy silt. Along the Colorado River, the upper 1 m of the flood plain deposits is commonly clean or humic and slightly silty, very fine to medium sand that locally contains a minor amount of pebbles and cobbles. Clasts are poorly to moderately well sorted, and unit is poorly to well bedded. Clasts are commonly subangular to rounded; their lithologies reflect those of the bedrock in the upstream areas. The unit occurs along the Colorado River and its major tributaries. Low-lying areas of the map unit are prone to periodic flooding. Deposits along tributary streams may contain more sand and silt than those along the Colorado River. The unit locally includes small alluvial-fan and debris-flow deposits (Qfy), low terrace deposits that are commonly less than 5 m above modern stream level, and sheetwash deposits (Qsw), and locally may include some organic-rich deposits. A thick (>15 m) sequence of flood plain deposits, which is exposed in gullies along West Elk Creek (NW _, sec. 16, T. 5 S., R. 91 W.), consists of interbedded sand and silt. This thick sequence of interbedded sand and silt may have been produced in part by damming of West Elk Creek by fan deposits from intermittent tributary drainages downstream of the sequence. The upper part of the unit may be a complex of cut-and-fill deposits of Holocene and late Pleistocene(?) age. The lower part of the unit is probably equivalent, at least in part, to the younger terrace alluvium (Qty), which is of late Pleistocene age. The unit is tentatively correlated with deposits in terrace T8 of Piety (1981) along the Roaring Fork River between Glenwood Springs and Carbondale, Colo. Sand and gravel has been mined in unit Qfp west of the map area near Silt Colo. and in the eastern part of the map area north of the Colorado River. Thickness along the Colorado River is more than 5 m along the western map area boundary and greater than 15 m near the eastern map area boundary (Colorado Highway Department, unpublished data); maximum exposed thickness is 15 m along West Elk Creek; maximum thickness along the Colorado River may be about 20 m (Colorado Highway Department, unpublished data)

Qty **Younger terrace alluvium (late Pleistocene)**—Stream alluvium that underlies terrace remnants that are about 12 m above the Colorado River, Divide Creek, and Elk Creek. Along the Colorado River, the lower part of the unit consists mostly of a poorly sorted, clast-supported, pebble- and cobble-gravel with a sand matrix. Where deposited by minor tributary streams, the upper part of the unit commonly consists of silty sand that contains lenses and thin (as much as 50 cm) beds of cobbly pebble gravel and pebbly sand. Clasts in the lower part of the unit are commonly subrounded to rounded and are derived from a variety of sedimentary, igneous, and metamorphic rocks in the upstream areas. Where deposited by minor tributary streams, the clasts in the upper part of the unit are basalt and sandstone on the south side of the Colorado River and are mostly sandstone on the north side of the river. Along Divide Creek, the unit is mostly a poorly sorted, clast-supported, bouldery, cobble- and pebble-gravel with a sand matrix. Near the mouth of Divide Creek, the unit is a gravelly silty sand that contains lenses of cobbly pebble gravel. Clasts are chiefly subrounded to rounded basalt. Along Elk Creek, the unit is poorly exposed, but it appears to consist mostly of poorly sorted, clast-supported, pebble- and cobble-gravel with a sand matrix. The unit along the Colorado and its major tributaries is overlain by about 2-3 m of loess (Qlo) and by younger fan-alluvium and debris-flow deposits (Qfy). Unit Qty is probably equivalent in part to outwash of the

Pinedale glaciation, which is about 12-35 ka. Unit Qty is tentatively correlated with deposits in terraces T7 and T6 of Piety (1981) along the Roaring Fork River between Glenwood Springs and Carbondale, Colo., and with deposits in terraces A and B of Bryant (1979) farther upstream between Woody Creek and Aspen, Colo. Exposed thickness is 15 m along the Colorado River and 5 m along Divide Creek; maximum thickness along the Colorado River is possibly 30 m

Qtm **Intermediate terrace alluvium (late Pleistocene)**—Alluvium that underlies small terrace remnants about 20-25 m above Elk, West Elk, and Divide Creeks. The unit is poorly exposed, but it appears to consist of poorly sorted, clast-supported, slightly bouldery, pebble- and cobble-gravel with a sand matrix. Clasts are mostly subangular to rounded sandstone, quartzite, granite (or gneiss), limestone, conglomerate, and siltstone. The unit is locally weakly cemented by fine-grained calcium carbonate and is locally overlain by loess (Qlo) and by thin, unmapped deposits of slopewash (Qsw) or colluvium (Qc). The unit is inferred to be intermediate in age between the younger and older terrace alluviums (Qty and Qto) and may be of middle or early Wisconsin age (about 35-65 or 65-80 ka; Richmond and Fullerton, 1986, fig. 2). Thickness is probably about 5-10 m

Qto **Older terrace alluvium (late middle Pleistocene)**—Stream alluvium that underlies terrace remnants about 40-45 m above the Colorado River, about 40 m above Divide, Garfield, and Elk Creeks, and about 45 m above West Elk Creek. Along the Colorado River, the unit is mostly a poorly to moderately well sorted, clast-supported, bouldery pebble- and cobble-gravel with a sand matrix that (1) is overlain by about 7-15 m of thin-bedded (1-15 cm), slightly silty sand and thin (5-25 cm) lenses of pebbly sand and sandy pebble gravel, or (2) grades upward into slightly cobbly pebble gravel and pebbly sand in the upper 2-3 m. Locally the unit is a pebble gravel that is overlain by about 3 m of thin bedded, sandy silt that contains thin (5-35 cm) lenses of sand and sandy pebble gravel. Locally the lower 1 m of the unit is weakly cemented by fine-grained calcium carbonate. Clasts are chiefly subrounded to rounded sandstone, gneiss, quartzite, basalt, granodiorite(?), limestone, and dolomite deposited by the Colorado River. Locally, the clasts in the upper part of the unit were deposited by streams tributary to the Colorado. They are basalt and a minor amount of sandstone near the mouths of Divide Creek and Garfield Creek and are sandstone near the mouths of intermittent tributary streams that head on the south flank of the Grand Hogback. Along Garfield Creek, the unit is mostly a poorly sorted, clast-supported, bouldery, pebble- and cobble-gravel with a sand matrix. Clasts are chiefly subrounded to rounded basalt. Some of the clasts are as long as 1 m. Along Divide Creek the unit is mostly a poorly sorted, clast-supported, bouldery, pebble- and cobble-gravel with a sand matrix. The unit locally contains a few thin (25-35 cm) lenses of sand and sandy pebble gravel. Clasts are chiefly subrounded to rounded basalt and a minor amount of sandstone. Locally the clasts in the upper part of the unit are chiefly subangular to subrounded sandstone and a minor amount of basalt. Some of the basalt clasts in the lower part of the unit are as long as 1.5 m. Along Elk and West Elk Creeks, the unit is mostly a poorly to moderately well sorted, clast-supported, cobbly pebble gravel with a sand matrix. The unit locally contains lenses and beds of pebbly sand and sandy silt that are about 5-100 cm thick and rare sandstone boulders, some as long as 1.7 m. Locally some of the beds are weakly cemented by fine-grained calcium carbonate and form small ledges that are as much as 1 m thick. Clasts are chiefly subrounded to rounded sandstone, quartzite, granite (or gneiss), limestone, conglomerate, and siltstone. The unit along the Colorado and its major tributaries is locally mantled by 2.5-4 m of loess (Qlo) and by older fan and debris-flow deposits (Qfo) and slopewash deposits (Qsw). Locally there is a buried soil in the upper part of the unit. This soil has an argillic B horizon that is 60 cm thick and was formed in silty alluvium or loess. It overlies a stage III K horizon, 120 cm thick in the upper part of the underlying gravel. The morphologic development of the soil suggests that the unit is of Bull Lake age (Hall and Shroba, 1993) and may be about 140-150 ka (Pierce and others, 1976; Pierce, 1979) or about 130-300 ka (late middle Pleistocene; Richmond, 1986, chart 1A). Locally the buried soil is formed in the lower of two loess sheets that locally mantle the unit. The unit is tentatively correlated with deposits in terraces T5 and T4 of Piety (1981) along the Roaring Fork River between Glenwood Springs and Carbondale and with deposits in terrace C of Bryant (1979) farther upstream between Woody Creek and Aspen. Sand and gravel has been mined in unit Qto at two sites in the map area. Exposed thickness along the Colorado River is 10-35 m and the maximum thickness is probably about 40 m. Exposed thickness is 3 m along Garfield Creek, 20 m along Divide Creek, 4-6 m along Elk Creek, and 15 m along West Elk Creek. Maximum thickness along these creeks is possibly 30 m

Qtt **Oldest terrace alluvium (middle Pleistocene)**—Stream alluvium that underlies small terrace remnants that are about 65, 75, and 100 m above the Colorado River, about 100 m above Elk Creek near its confluence with East Elk Creek, and about 100 m above Garfield Creek near its confluence with the Colorado River. Along the Colorado River and Elk Creek, the unit is mostly a poorly sorted, clast-supported, slightly bouldery, pebble- and cobble-gravel with a sand matrix. It locally consists of thin (0.5-35 cm) lenses and beds of silt, sandy silt, silty sand, and sandy pebble gravel. The unit locally grades upward into about 30-50 cm of moderately well sorted, clast-supported, pebble gravel with a sand matrix that is overlain by about 50-75 cm of non-pebbly to slightly pebbly, slightly silty sand. Clasts are mostly subrounded to rounded and are derived from a variety of sedimentary, igneous, and metamorphic rocks in the upstream areas. Locally along the Colorado River, the upper part of the unit was deposited by tributary streams and is composed of angular to subrounded sandstone or basalt clasts with a sand matrix. A stage III K soil horizon, 60-90 cm thick, is locally present in the top of the unit and the lower 1-2 m of the unit is locally weakly cemented by fine-grained calcium carbonate. Along Garfield Creek, the unit is mostly a poorly sorted, clast-supported, bouldery, basalt-rich gravel that contains a minor amount of sandstone and quartzite clasts. The basalt clasts are subrounded to rounded and are as long as 2 m. The unit along the Colorado River and its major tributaries is mantled in some places by 2-4 m of loess (Qlo) and in other places by about 5-10 m of sandstone-rich older fan-alluvium and debris-flow deposits (Qfo), which are overlain by loess. The loess mantle locally consists of two or more sheets. The unit is probably younger and older than the 90-m terrace deposits, which occur within 50 km of the map area, that contain or are overlain by the 620-ka Lava Creek B volcanic ash. The unit is tentatively correlated with deposits in terraces T3 and T2 of Piety (1981) along the Roaring Fork River between Glenwood Springs and Carbondale and with deposits in terrace D of Bryant (1979) farther upstream between Woody Creek and Aspen. Exposed thickness is commonly 2-10 m and locally 20 m along the Colorado River, 10 m along East Elk Creek, and 4 m along Garfield Creek; maximum thickness along the Colorado River is possibly 25 m

Tg **Gravel (Pliocene or Miocene)**—Four deposits about 700-760 m above the Colorado River near the northeastern corner of the map area. Well rounded cobbles and boulders as large as 0.5 m in diameter of very pale-orange quartzite, light-gray to medium-gray limestone and dolomite, and light-brownish-gray to medium-light-gray gneiss were found on and near ridge crests. Clast compostion suggests a source to the north. The shape of the largest deposit suggests that it is a western remnant of a northeast-southwest oriented channel because its contact slopes significantly to the southeast. A similar but smaller deposit that slopes toward the northwest occurs about 900 m to the east and may be a remnant on the opposite side of the channel. Exposures of the clasts are few and very poor, and no evidence of imbrication could be seen. The clasts are similar in composition and the gravel (Tg) may be somewhat similar in age to the younger gravel (Tgy) in the adjacent Storm King Mountain quadrangle, where the gravel is about 815 and 920 m above the Colorado River (Bryant and Shroba, 1997). The largest deposit is about 40-80 m thick

ALLUVIAL AND COLLUVIAL DEPOSITS—Clay, silt, sand, and gravel in flood plains and in fans on flood plains and terraces; in pediment deposits on a gently sloping surface cut on bedrock; and in sheets of pebbly silty sand that locally mantle valley bottoms and the adjacent valley sides and hill slopes

Qfy **Younger fan-alluvium and debris-flow deposits (Holocene and latest Pleistocene)**—Mostly poorly sorted, clast- and matrix-supported, slightly bouldery pebble- and cobble-gravel with a silty sand matrix, and locally pebbly and cobbly silty sand that contains thin (10-40 cm) lenses of sand, pebble gravel, and cobbly pebble gravel. Deposits derived from the Mancos Shale, especially the upper member (Kmu), have a clayey matrix that is sticky when wet and has prominent shrinkage cracks when dry. Some of these deposits contain expansive clays and may have high shrink-swell potential. The unit locally contains boulders as long as 3.5 m; some of the larger boulders were probably deposited by debris flows. In general, the unit is nonbedded to poorly bedded; beds are commonly less than 1 m thick. At the mouth of Alkali Creek, the unit is mostly very thin-bedded (0.5-2 cm) sandy silt. Clasts are commonly angular to subangular sandstone north of the Colorado River and are angular to subangular sandstone and angular to subrounded basalt south of the Colorado River. The unit is undissected and was deposited chiefly by small intermittent streams graded to the flood plains of modern streams (Qfp) and locally to the tops of terraces that are underlain by younger terrace alluvium (Qty). Locally the unit includes sheetwash deposits (Qsw) and colluvium (Qc). Surface is locally subjected to flooding and debris-flow deposition. Exposed thickness is 3-16 m; maximum thickness probably about 25 m

Qac **Undivided alluvium and colluvium (Holocene and late Pleistocene)**—Chiefly undifferentiated flood plain and stream-channel deposits (Qfp), young fan-alluvium and debris-flow deposits (Qfy), debris-flow deposits (Qd), and sheetwash (Qsw) deposits. The alluvium typically consists of interbedded sand, pebbly sand, and pebble gravel and ranges from thin-bedded (0.5-15 cm) clayey, silty sand to thick-bedded (>1m), poorly sorted, clast- and matrix-supported, slightly bouldery, pebble- and cobble-gravel with a sand matrix. Sheetwash deposits are typically clayey silt to pebbly sand. Low-lying areas of the map unit are prone to periodic flooding and debris-flow deposition. Deposits derived from the Mancos Shale commonly contain more silt and clay than those derived from other bedrock units. Deposits that are composed of well sorted and silty sand are prone to gullying and piping. Some of the deposits derived from the Mancos Shale, especially the upper member (Kmu), contain expansive clays and may have high shrink-swell potential. Alluvial deposits form flood plains, low terraces, and small fans along small perennial streams and some of the larger intermittent streams that are tributary to the Colorado River. Sheetwash deposits locally mantle the valley bottoms and the adjacent valley sides and hill slopes. Exposed thickness: alluvium is 1-8 m; colluvium is 1-1.5 m. Maximum thickness is probably about 15 m

Qfo **Older fan-alluvium and debris-flow deposits (late and middle Pleistocene)**—Mostly poorly to very poorly sorted, clast- and matrix-supported, slightly bouldery, pebble- and cobble-gravel with a silty sand matrix, sandy pebble gravel, pebbly sand, and locally pebbly and cobbly silty sand. Clasts are chiefly angular to subangular basalt and a minor amount of sandstone in deposits on the south side of the Colorado River and angular to subrounded sandstone in deposits on the north side of the river. Map unit is nonbedded to poorly bedded; commonly contains discontinuous beds and lenses. The unit has a slightly dissected surface that is mantled by about 1-3 m of loess (Qlo). The unit was deposited by Baldy Creek (near the southeastern corner of the map area) and by small intermittent streams graded to tops of terrace remnants composed of older terrace alluvium (Qto) along Divide Creek. Locally the unit includes sheetwash deposits (Qsw). Exposed thickness is 2-10 m; maximum thickness is possibly 25 m

Qp **Pediment deposits (middle Pleistocene)**—Gravelly alluvium and debris-flow deposits at four or more levels that overlie gently sloping surfaces cut on Mancos Shale (Km) and Wasatch Formation (Tw). Locally as much as 6 m of relief on the pediment (bedrock surface) where it is incised by stream channels (Shroba, 1996). Mostly poorly sorted, clast-supported, bouldery, pebble- and cobble-gravel with a sandy silt matrix and poorly sorted, cobbly, sandy pebble gravel to pebbly silty sand. Clasts are chiefly angular to subrounded sandstone and locally minor amounts of siltstone, limestone, and quartzite. The quartzite clasts are subrounded to rounded and were probably derived from older fluvial surficial deposits. Nonsorted, bouldery, debris-flow(?) deposits are locally common in the upper part of the unit. Some of the sandstone boulders near the Grand Hogback are as long as 3 m. A stage III K soil horizon is locally present in the upper 50-75 cm of the unit, and some of the sandstone cobbles in the upper 2 m are weathered and disintegrated to sand-size particles. The bedrock beneath the unit is locally slightly oxidized to a depth of 3 m or more. The unit is dissected and is mantled by about 2-4 m of loess (Qlo), which locally consists of two or more sheets. A reddish-yellow (5YR 6/6) argillic B horizon, 60 cm thick, is locally present in the top of the basal loess sheet. The lower limits of the pediment deposits are about 40-100 m above Elk and West Elk Creeks and about 40-190 m above the Colorado River. The three lower pediment deposits along the Colorado River east of New Castle appear to be graded to terrace remnants composed of old terrace alluvium (Qto and Qtt) that are about 40-45, 65, and 75 m above the river. Some of the loess (Qlo) on gently sloping surfaces along the Colorado River and on the east side of Garfield Creek may overlie pediment deposits. Exposed thickness is commonly 2-5 m; maximum observed thickness is 10 m; maximum thickness is possibly 15 m

Qbg **Basaltic gravel (middle Pleistocene)**—Small basaltic gravel deposits that form remnants of terraces(?) along small tributaries 75, 100, and 160 m above Divide Creek in the southwestern part of the map area. These deposits are found on tops of hills and on small benches on hillsides. The unit is not exposed; basaltic clasts 0.2-1.5 m in diameter litter the surface. Thickness of unit is estimated to be less than 4 m

Qbb **Basaltic boulder gravel (middle or early Pleistocene)**—Bouldery pediment(?) deposits consisting mainly of alluvium and debris-flow deposits and possibly minor fan deposits at two levels that overlie gently sloping surfaces cut on Wasatch Formation (Tw) in the southern part of the map area. These surfaces are about 195-255 m above Divide Creek and are about 160-170 m below the adjacent geomorphic surface that is underlain by high-level basaltic alluvium (QTba). The unit is poorly exposed, but it locally consists of very poorly sorted, clast-supported, very bouldery cobble gravel with a sand matrix. Clasts are subangular to subrounded basalt that are commonly greater than 1 m long and are as long as 2 m. The gravel is locally mantled by about 1-1.5 m of non-pebbly to pebbly, slightly silty sand. A stage III K soil horizon, 60 cm thick, is formed in the top of the unit. The K horizon is mantled by loess (Qlo) that is at least 50 cm thick. The unit is probably locally mantled by sheetwash deposits (Qsw). Exposed thickness is 4-6 m; maximum thickness is possibly 20 m

QTba **High-level basaltic alluvium (early Pleistocene or late Pliocene)**—Fan(?) alluvium and debris-flow deposits and valley-fill or pediment(?) deposits that underlie gently sloping geomorphic surfaces in the southern part of the map area that are more than 285 m above the Colorado River, about 285-440 m above Divide Creek, and about 290 m above Garfield Creek. The northern part of the unit underlies a gently west-sloping geomorphic surface. It is a 45-m-thick sequence of alluvial-fan(?) deposits that consists of basaltic stream alluvium and debris-flow deposits. These deposits are well exposed in a steep landslide scarp (NE _, SE _, sec. 7, T. 6 S., R. 91 W.) where they consist of alternating lenticular beds and lenses (about 10 cm-2 m thick) of mostly poorly bedded, poorly sorted, clast-supported, very bouldery, cobble- and pebble-gravel and cobbly pebble gravel with a matrix of slightly silty sand. The sequence also includes minor amounts of poorly sorted, sandy pebble gravel, pebbly sand, and sand. The clasts are mostly subangular to rounded basalt and a minor amount of sandstone and intrusive igneous rocks. Basalt clasts are commonly 2 m long and are as long as 4.5 m. A soil K horizon, 120 cm thick, is formed in pebbly, sandy alluvium at the top of the sequence. The K horizon has stage IV carbonate morphology in the upper 60 cm and stage III morphology in the lower 60 cm. The K horizon is overlain by at least 5.5 m of loess (Qlo), which consists of at least five separate loess sheets, about each 1-1.2 m thick. Where exposed, the sequence of alluvial-fan deposits overlies Wasatch Formation (Tw), but these deposits may locally overlie or be interstratified with unexposed gravelly alluvium deposited by the Colorado River. The presence of underlying or interstratified

Colorado River alluvium is suggested by the lithologic composition of the colluvial deposits derived from the alluvial-fan deposits. These colluvial deposits locally contain a minor amount of rounded and well rounded pebbles and cobbles that are identical to those in nearby, but younger and topographically lower, terrace deposits that were laid down by the Colorado River. The southern part of the unit underlies a gently, north-sloping geomorphic surface and is poorly exposed. It appears to be either valley-fill or pediment(?) deposits that consist of bouldery alluvium and colluvium that accumulated on a former valley floor or on a pediment(?) surface cut on the Wasatch Formation (Tw). These deposits are probably mostly poorly sorted, clast-supported, bouldery, cobble- and pebble-gravel with a sand matrix. The clasts are mostly subangular to rounded basalt that are as long as 2 m. These gravelly deposits are mantled by loess deposits (Qlo). The southern part of the unit may have been deposited by ancestral Garfield Creek and(or) Baldy Creek. Exposed thickness of fan(?) deposits in the northern part of the unit is 45 m; thickness of valley-fill or pediment(?) deposits in the southern part of the unit is possibly as much as 25 m

COLLUVIAL DEPOSITS—Silt, sand, and gravel on valley sides and hill slopes that were mobilized, transported, and deposited by gravity and sheet erosion

Qc **Colluvium, undivided (Holocene and late Pleistocene)**—Mostly clast-supported, pebble, cobble, and boulder gravel with a silty sand matrix, and gravelly silty sand, sandy silt, and clayey silt. Deposits derived from the Mancos Shale (Km) commonly contain more silt and clay than those derived from the other bedrock units. Deposits derived from the upper member of the Mancos Shale (Kmu), shale and (possibly) mudstone from the Mesaverde Group (Kmv), and (probably) shale from the Morrison Formation (Jm) contain expansive clays and locally may have high shrink-swell potential. Small unmapped deposits derived from the Eagle Valley Evaporite (hee) are prone to hydrocompaction and subsidence because of the dissolution of gypsum, anhydrite, and possibly halite. These minerals are damaging to untreated concrete and uncoated steel. The unit is typically unsorted to poorly sorted and unstratified to poorly stratified. Clasts are typically angular to subrounded; their lithologic composition reflects that of the bedrock and(or) the surficial deposits from which the colluvial deposits were derived. The unit locally includes sheetwash (Qsw) creep, debris-flow (Qd), landslide (Qls), rock-fall, and undivided alluvium and colluvium (Qac) deposits that are too small to map separately or that lack distinctive surface morphology and could not be distinguished in the field or on aerial photographs. The map unit also locally includes thin loess (Qlo) mantles on older gently sloping colluvial deposits, small deposits of alluvium and colluvium (Qac) in and along minor drainageways, and probably small pediment deposits (Qp) on the north side of the Grand Hogback. Exposed thickness is 2-4 m; maximum thickness is probably about 5 m

Qd **Debris-flow deposits (Holocene to middle Pleistocene)**—Lobate and fan-shaped masses of debris that were deposited by sediment-charged flows and commonly overlie gently sloping surfaces on the north flank of the Grand Hogback and on the south flank of the White River uplift in the northern part of the map area. Deposits are chiefly very poorly sorted and very poorly stratified boulders to granules supported in a matrix of slightly clayey silty sand to slightly sandy silty clay and locally include lenticular beds of poorly sorted, clast-supported bouldery, cobbly pebble gravel with a silty sand matrix. Clasts are commonly randomly oriented and angular to subangular. Clasts in deposits north of the Colorado River are mainly sandstone. Clasts in deposits south of the Colorado River are mainly basalt and sandstone. Some of the deposits are probably mantled by loess (Qlo) and locally by other colluvial deposits in their steep upper parts. Debris flow deposits commonly occur on and downslope of the Maroon Formation (Phm), Mancos Shale (Km), and the Wasatch Formation (Kw). Deposits derived from the upper member of the Mancos (Kmu) contain expansive clays and locally may have high shrink-swell potential. Low-lying areas of the map unit that are adjacent to stream channels are prone to periodic flooding and debris-flow deposition. The lower extent of the debris-flow deposits locally ranges from less than 5 m above unnamed intermittent streams to as much as 90 m above West Elk Creek. Exposed thickness is about 6 m; maximum thickness is possibly 30 m

Qsw **Sheetwash deposits (Holocene and late Pleistocene)**—Mostly pebbly, silty sand and sandy silt that are derived chiefly from weathered bedrock and loess (Qlo) by sheet erosion. Common on gentle to moderate slopes in areas underlain mostly by the Maroon Formation (Phm), Mancos Shale (Km), and Wasatch Formation (Tw). Low-lying areas of the map unit are prone to periodic sheet flooding. The unit locally includes small deposits of loess (Qlo) and undivided alluvium and colluvium (Qac) in and along minor drainageways; may locally include creep in colluvium (Qc) and alluvial-fan and debris-flow deposits (Qfy). Exposed thickness is 2-5 m; maximum thickness is probably about 10 m

Qls **Landslide deposits (Holocene and late Pleistocene)**—Chiefly unsorted and unstratified rock debris characterized by hummocky topography. Many of the landslides are complex (Varnes, 1978) and commonly form on unstable slopes that are underlain by the Eagle Valley Formation (hev), Maroon Formation (Phms, Phmm, Phmw, Phml), Morrison Formation (Jm), Dakota Sandstone (Kd), Mancos Shale (Kmu, Kmn, Kmjl, Kmj, Kml), Iles Formation (Ki, Kir, Kicc), Williams Fork Formation (Kwf, Kwfl, Kwfu), and Wasatch Formation (Tws, Twss, Twm, Twav, Twal) in various parts of the map area. The younger deposits are commonly bounded upslope by crescentic headwall scarps and downslope by lobate toes. The unit includes debris-slide, rock-slide, debris-slump, rock-slump, slump-earth-flow, earth-flow, and debris-flow deposits as defined by Varnes (1978). The sizes and lithologies of the clasts and the grain-size distributions of the matrices of these deposits reflect those of the displaced bedrock units and surficial deposits. Landslide deposits are prone to continued movement or reactivation due to natural as well as human-induced processes. Deposits derived from the Maroon Formation, the Dakota Sandstone, the Williams Fork Formation, and the Iles Formation may contain blocks of rock as long as 5 m. Landslide deposits derived from the Mancos Shale and the Wasatch Formation are rich in clay. Mancos-derived clay, especially from the upper member (Kmu) contain expansive clay and locally may have high shrink-swell potential. Deposits derived from the Eagle Valley Evaporite are prone to hydrocompaction and subsidence because of dissolution of gypsum, anhydrite, and possibly halite. These minerals are damaging to untreated concrete and uncoated steel. In the south-central part of the map area, a landslide about 2 kilometers long involving the Shire Member (Tws) of the Wasatch Formation and several surficial deposits has moved downslope about 20 m, essentially intact. Where rock units can be mapped in landslide deposits, they are identified by their map unit symbols in parentheses. The unit locally includes unmapped sheetwash (Qsw) and creep-derived colluvium (Qc) deposits. Exposed thickness is 2-5 m; maximum thickness is possibly 50 m

EOLIAN DEPOSITS—Wind-deposited sand, silt, and clay that mantles level to gently sloping surfaces

Qlo **Loess (late and middle? Pleistocene)**—Wind-deposited, nonstratified, friable when dry, slightly plastic to plastic when wet, calcareous (6-18 percent calcium carbonate), slightly clayey, sandy silt. The grain-size distribution of the carbonate-free fraction of unweathered loess in and near the map area commonly consists of 22-46% sand (2-0.05 mm), 43-62% silt (0.05-0.002 mm), and 15-18% clay (<0.002 mm). About 55-75% of the unweathered loess is composed of very fine sand (0.01-0.05 mm) plus coarse silt (0.05-0.02 mm). Median grain size ranges from 0.03 to 0.05 mm (Shroba, 1994). The unit is prone to sheet erosion, gullying, piping and hydrocompaction due to several factors including its low dry density (about 1,440 kg/m^3), grain size, sorting, and weakly developed vertical desiccation cracks. Locally includes some loess-derived sheetwash (Qsw) and creep-derived colluvium (Qc) deposits that are too small to map. Deposited during five or more episodes of eolian activity. Deposition may have continued into Holocene time. Possible sources for the loess include flood-plain deposits of the Colorado River and its major tributaries, sparsely vegetated outcrops of Tertiary siltstone and mudstone in the Piceance Basin west of the map area (Tweto, 1979), and large areas of exposed sandstone in the Canyonlands region in southeastern Utah (Whitney and Andrews, 1983). However, the relatively high content of very fine sand and coarse silt and the relatively high coarse silt/total silt ratios (about 0.7) of the unweathered loess suggest (1) a relatively short distance of eolian transport and (2) that the flood plain of the Colorado River, which aggraded primarily during glacial times in response to glacial and periglacial activity upstream, is the likely source of much of the loess (Shroba, 1994). The mapped distribution of loess is approximate because it lacks distinct topographic expression. The unit commonly mantles level to gently sloping surficial deposits as old as or older than the younger terrace alluvium (Qty). Younger terrace alluvium (Qty) is mantled by one loess sheet. Older terrace alluvium (Qto) is locally mantled by two loess sheets. Pediment deposits (Qp) and the oldest terrace alluvium (Qtt) are locally mantled by two or more loess sheets, and the high-level basaltic alluvium (QTba) is mantled by five or more loess sheets. The soil that is formed in the upper loess sheet on the older terrace alluvium commonly consists of the following sequence of horizons: an organic-enriched A horizon about 20 cm thick; a cambic B horizon about 10-20 cm thick; a weak to moderate prismatic, argillic B horizon about 20-40 cm thick; and a stage I Bk horizon greater than 75 cm thick. The soil that is formed in the lower loess sheet on the older terrace alluvium contains more clay and calcium carbonate than the soil in the upper loess sheet and commonly consists of the following horizons: a cambic B horizon about 20 cm thick; a moderate to strong prismatic, argillic B horizon about 55-75 cm thick that contains weak stage I-II calcium carbonate; a weak stage III K horizon about 40 cm thick; and a stage I-II Bk horizon from about 30 to greater than 60 cm thick. Where the upper loess sheet is composed of very sandy silt, the soil formed in it has a weakly developed, non-prismatic argillic B horizons that is about 35 cm thick. If the upper and lower loess sheets on the older terrace alluvium correlate with loess units A and B, respectively, that are on and adjacent to the eastern Snake River Plain in eastern Idaho, then (1) the uppermost loess sheet in the map area accumulated between about 10-70 ka and is of late Pleistocene age and (2) the underlying loess sheet accumulated during an interval that ended shortly after 140-150 ka and is partly or entirely of latest middle Pleistocene age (Pierce and others, 1982). Exposed thickness is 1.5-5.5 m; commonly 2-4 m thick. Maximum thickness is possibly 8 m

BEDROCK UNITS

Tw **Wasatch Formation (early Eocene to Paleocene)**—Formation symbol (Tw) shown in cross section only. Formation includes three members: the Shire, the Molina, and the Atwell Gulch Members. Based on drill hole data and map relations, about 1.2 km of the formation are exposed

Tws **Shire Member**—Nonmarine, predominantly multicolored fine-grained clastic intervals of thick claystone, mudstone, and siltstone interbedded with less abundant intervals of minor coarse-grained clastic beds of thin fluvial sandstone, as defined by Donnell (1969) at Shire Gulch about 5 km southeast of DeBeque, Colo., approximately 70 km west southwest of New Castle. Colors in the intervals of fine clastic beds include pale red, moderate pink, light red, pale reddish brown, pale purple, pale red purple, pinkish gray, light gray, medium light gray, light brownish gray, brownish gray, light olive gray, greenish gray, yellowish gray, and moderate yellow. Discontinuous, thin (1-15 cm) beds of siltstone of similar colors form less than 1% of the fine clastic intervals. Colors of the sandstone beds include yellowish gray, grayish yellow, light gray, and light olive gray. In general, sandstone, which forms less than 3% of the member, is commonly crossbedded, locally displays channels 0.3-3 m deep and 5-20 m wide and contains coarse sand and lenses of pebble conglomerate at the base of many channels. The clasts are generally medium grained, are moderately sorted, and consist of about 50% quartz, 30% feldspar, and 20% rock fragments and weathered mafic grains. In sparse localities minor amounts of carbonaceous films are present on sandstone bedding planes, and the sandstone has a weak calcareous cement. Landslides at several scales are common on the Shire Member and pose a significant geologic hazard to roads, pipelines, and structures in the southern half of the map area. The largest slide (rock slump) is about 2 km long and nearly 1 km wide in the south-central part of the map area where the western side of a loess- (Qlo) and a high-level basaltic alluvium- (Qtba) covered mesa has slid downward about 20 m, essentially intact. The Shire Member includes a prominent sandstone unit (Twss) described below. Based on drill hole data and map relations, about 1.2 km of the Shire Member are exposed

Twss **Sandstone unit**—Calcareously cemented, grayish-yellow to yellowish-gray, medium-grained sandstone interbedded with minor fine-grained clastic intervals similar to those described in the Shire Member (Tws). This informal unit is first described in this report, forms a prominent sandstone-capped cuesta 2-3 km north of the eastern half of the southern boundary of the map area, and is also exposed on the western boundary of the map area about 0.3 km north of the Colorado River. The sandstone is estimated to be 60-80 m thick

Twm **Molina Member**—Nonmarine, predominantly multicolored fine-grained clastic intervals consisting of thick claystone, mudstone, and siltstone interbedded with less abundant coarse-grained clastic intervals of thin fluvial sandstone, defined by Donnell (1969) near the town of Molina, Colo., 63 km to the southwest of the town of New Castle. Donnell described exposures as possibly Molina equivalent about 12 km west-northwest of the map area, at the south side of Rifle gap. These exposures at Rifle Gap have been physically traced southeastward in the Rifle quadrangle (Shroba and Scott, 1997), through the intervening Silt quadrangle based on unpublished mapping (R.B. Scott) to the New Castle quadrangle. The fine-grained clastic beds are similar to those described above for the Shire Member. The Molina Member is distinguished from the Shire Member by the presence of about 20 percent sandstone beds that are more resistant than those of the Shire because of a stronger calcareous cement; these sandstone beds form a low cuesta that can be traced across the central part of the map area. Sandstone of the Molina is medium-grained, is very pale orange, grayish orange, yellowish gray, and grayish orange, and commonly contains 1-4 cm long claystone rip-up clasts. Clasts are moderately sorted and consist of about 65% quartz, 25% feldspar, and 10% dark rock fragments and mafic minerals; a trace of muscovite is present. Although the sandstone is crossbedded, cut by channels, and slightly conglomeratic at the base of channels, the sandstone beds of the Molina Member are more continuous than those in the Shire Member. The map unit ranges from 210-280 m thick

Twa **Atwell Gulch Member**—Member symbol (Twa) shown in cross section only. The Atwell Gulch Member was defined by Donnell (1969) based on exposures in Atwell Gulch west of the town of Molina, Colo., 63 km southwest of New Castle. Donnell recognized exposures as Atwell Gulch equivalent about 12 km west-northwest of the Grand Hogback in the map area, at the south side of Rifle Gap. Member includes a volcaniclastic-rich unit and a lower unit. Member is about 260 m thick in southeast exposures, is as much as 400 m thick north of the Colorado River, and is about 240 m thick in western exposures, but drill hole data suggest that the unit thins to 70 m in the southwest part of the map area

Twav **Volcaniclastic-rich unit**— Nonmarine, predominantly multicolored fine-grained clastic intervals consisting of thick claystone, mudstone and siltstone interbedded with less abundant intervals consisting of coarse-grained volcaniclastic beds of fluvial sandstone and abundant conglomerate. The fine-grained clastic intervals are commonly greenish gray, light gray, pale purple, pale pink, moderate red, and pale reddish brown. Siltstones are more common than in overlying members of the Wasatch Formation. Coarse-grained clastic intervals of the map unit form low hills that stand above the pediment surfaces, in contrast to the less resistant fine-grained clastic intervals that have been eroded to the level of pediment surfaces. About 15- 45% of the volcaniclastic-rich unit consists of coarse-grained clastic beds of sandstone and conglomerate that range from 1-20 m thick. The sandstones are predominantly medium- to coarse-grained and sparsely fine-grained and are greenish gray, light-olive gray, dark greenish gray, and light gray. The clasts in the unit range from poorly sorted to well sorted; the clasts are almost exclusively andesitic, range in size from fine sand to cobbles, and contain distinct phenocrysts of augite and plagioclase; clasts of isolated biotite crystals are common. The map unit displays common crossbedding, channels, and conglomerate-rich lower parts of channels; locally, soft-sediment deformation has contorted the bedding of the sandstones, in places with meter-size overturned structures. The more conglomeratic parts of the unit are more resistant and are moderately cemented, and the finer sandstone parts containing sparse conglomerate are generally very poorly cemented by calcium carbonate. The more conglomeratic layers form small ridges that can be traced along strike within the unit. Exposures of the volcaniclastic-rich unit range from 210 m on the eastern side of the map area, to about 240 m north of the Colorado River, and 90 m on the western side

Twal **Lower unit**—Nonmarine, predominantly multicolored fine-grained clastic intervals consisting of thick siltstone, mudstone and claystone interbedded with less abundant intervals consisting of coarse-grained clastic beds of relatively thin fluvial sandstone and sparse conglomerate. Multicolored fine-grained intervals are largely siltstone and mudstone; colors range from very light gray, light gray, light brownish gray, pale olive, and light olive gray to brownish gray. The coarse-grained clastic intervals form less than 10% of the unit, range from 1 to 5 m thick, and are brownish gray, pale yellowish brown, grayish green, and very pale orange. In the coarse-grained clastic intervals, clasts are poorly to moderately sorted, weakly cemented by calcium carbonate, and typically consist of about 50% quartz, 30% feldspar, 10% muscovite and biotite flakes, and 10% rock fragments and altered mafic minerals. The abundance of volcanic clasts in the coarse-grained intervals decreases downward in the unit; sparse pebbles of andesitic composition are present near the top of unit but are absent near the base. Determination of the base of the lower unit of the Wasatch Formation is difficult. At some localities the sandstone contains more muscovite and biotite than the underlying Williams Fork Formation. Sparse conglomeratic layers are generally restricted to the base of the unit and contain clasts of predominantly white to very pale orange chert and rare pebbles and cobbles of quartz phenocryst-bearing rhyolite. Where rhyolitic volcanic clasts are absent above the base and biotite-bearing clasts are not present, the map unit is difficult to distinguish from the underlying sandstone beds of the Williams Fork Formation (Kwf) of the Mesa Verde Group. At these localities the lower contact of the unit is based upon the lower relief on the more readily eroded Wasatch Formation compared to the higher relief on the resistant, well cemented Williams Fork Formation. At some of these localities, particularly near the eastern boundary of the map area, the base of the lower unit is similar to the Paleocene Ohio Creek Formation of Tweto and others (1978) or to the Ohio Creek Member of the Williams Fork Formation, identified by dating of palynomorphs by Johnson and May (1980). In the absence of dated palynomorphs in the map area and because of the sparsity of conglomerate that contains volcanic clasts at the base of the lower unit, the age of the rocks mapped above the base of the lower unit remains mostly undetermined. A minor angular unconformity is present at Rifle Gap, 12 km to the northwest along the hogback, where Wasatch Formation strata containing rare rhyolitic pebbles dip about 10^{o} greater than the underlying Mesaverde Group strata. Carbonaceous films and clasts commonly found in the lower unit may be reworked from the Williams Fork. Although there is no evidence of an angular unconformity in this map area, the presence of minor reworked(?) coal fragments and sparse conglomerates that do not contain rhyolitic clasts suggests that there may be a minor unconformity below the lower unit. However, given the difficulty of determining the age of the strata, mentioned above, the nature and age of such an unconformity is also questionable. Because of the ambiguities of the assignment of this unit to either the uppermost part of the Upper Cretaceous Williams Fork Formation or the lowest part of the Paleocene Wasatch Formation, a cursory palynology (pollen and spores from plants) study involving several samples has been initiated to determine the age of the strata. Initial results (Farley R. Flemming, written communication) are provided in quotes in the following information: Sample 215 was collected by Bruce Bryant along road exposures south of the Colorado River from the volcaniclastic-rich unit (Twav) of the Atwell Gulch Member at the top of the lowest conglomerate bed that contains clasts of Tertiary andesitic rock (see map for locality). “The palynomorph assemblage from this sample is sparse and preservation is poor”; the age of the palynomorph “assemblage is Campanian [Upper Cretaceous]”; one specimen of the Campanian species *Aquilapollenites trialatus* has been reported along with several species and genera that are present in both Cretaceous and Tertiary rocks, abundant cuticular debris, sparse dinoflagellates, and no species restricted to the Tertiary. We interpret these observations to indicate that the assemblage was reworked from the Upper Cretaceous Williams Fork Formation. Sample 119 was collected below the volcaniclastic-rich unit of the Atwell Gluch Member by Bruce Bryant about 10.5 km to the east-southeast of sample 215 in the Storm King Mountain quadrangle; this sample contains well preserved pollen and spores; "one species of *Aquilapollenites reticulatus* indicates a Maastrichtian (Upper Cretaceous) age". We interpret these observations to indicate that the rock immediately beneath the volcaniclastic-rich unit of the Atwell Gulch Member may be part of the Upper Cretaceous Williams Fork Formation. Sample 232 was collected by Bruce Bryant along road exposures south of the Colorado River from the middle of the lower unit of the Atwell Gulch Member (see map for locality). "The palynomorph assemblage from this sample is fair and preservations is fair." "The assemblage contains one species that is resticted to the Upper Cretaceous (*Proteacidites retusus*) and no species that are restricted to the Tertiary." "This suggests that the assemblage is from the Upper Cretaceous." However, we consider the lithologic character of the unit from which sample 232 was collected to be typical of the Wasatch Formation and not typical of the Williams Fork Formation. Therefore, we suspect that erosion of the Williams Fork may have reworked this Cretaceous assemblage into Wasatch strata, and thus, we assign a Tertiary age to this unit. However, until we receive more definitive palynological data from sample 232 and rocks below the sample, the age of the lower unit of the Atwell Gulch Member as mapped here remains in question. Exposures of the lower unit are about 70 m thick on the eastern side of the map area, are about 160 m thick north of the Colorado River, and are about 150 m thick on the western side

Kmv **Mesaverde Group rocks undivided (Upper Cretaceous)**—Group symbol (Kmv) shown in cross section only. Group includes the Williams Fork Formation (Kwf) and the underlying Iles Formation (Ki). Group is about 1,400 m thick at exposures along section A-A' and thins to about 1,260 m thick as indicated by drill hole data along the southwestern part of section A-A'

Kwf **Williams Fork Formation**—Mudstone and siltstone predominate over intervals of sandstone, shale, thin coal, and burnt coal (clinker). Unit is largely nonmarine. Mudstone and siltstone are light olive gray, greenish gray, light brownish gray, and light gray and are poorly exposed between sandstone layers. Sandstone intervals form about 30% of the formation and are 1-50 m thick and massive but contain channels and crossbeds; conglomeratic sandstones are sparse. The sandstone ranges from yellowish gray and light brownish gray to very light gray, is cemented with calcium carbonate and silica, and is moderately sorted. Clasts in the sandstone consist of about 50% quartz, 35% feldspar, 15% rock fragments and dark mafic minerals; a trace of biotite and muscovite is generally present. Toward the base of the unit the sandstone intervals become more continuous and have been mapped separately as the upper sandstone unit (Kwfu) and lower unnamed sandstone unit (Kwfl), both described below. The wedge of finer clastic material below the lower of these two sandstone units is in part a medium-gray fissile shale that contains coquina deposits of pelecypods including oysters. The coquina contains detrital shells and fragments of *Corbula* and *Crassostrea* set in matrices of coarse- to medium-grained sandstone, indicative of a brackish water environment (W.A. Cobban, USGS, personal commun). The base of the formation is defined as the base of this shale unit and rests on the Rollins Sandstone Member of the Iles Formation. Burning of coal beds above and below the upper sandstone unit (Kwfu) and below the lower sandstone unit (Kwfl) baked the shales and sandstones on either side of the coal; these baked zones were mapped as clinker zones (Kmvb) that indicate the general position of past coal beds. Thin, < 1-2-m-thick layers of blackish-brown to grayish-black lignitic to bituminous coal layers are present and are shown by dashed lines; located on the first and third ridge northwest of the Colorado River stratigraphically above the upper unnamed sandstone unit (Kwfu). Exposures of the Williams Fork Formation are about 1,100 m thick along section A-A'

Kwfu **Upper unnamed sandstone unit**—Yellowish-gray, medium-grained, well sorted sandstone interval commonly containing thin, laminated bedding, parallel-bedding, and some crossbedding. Map unit ranges from about 30 to 50 m thick

Kwfl **Lower unnamed sandstone unit**— Yellowish-gray, medium-grained, well sorted sandstone interval containing thin laminated bedding and parallel-bedding. Map unit ranges from about 25 to 40 m thick

Ki **Iles Formation**—Marine shale and nonmarine sandstone and siltstone. Formation includes from top down, the Rollins Sandstone Member (Kir), an upper tongue of marine shale, and two sandstones, the Cozzette and Corcoran Sandstone Members undivided (Kicc), separated by a lower tongue of marine shale. Marine shales are monotonous sequences of medium dark gray to light olive gray fissile shale lithologically similar to the Mancos Shale (Km), described below. The base of the Corcoran Sandstone Member overlies the Mancos Shale. The Iles Formation is about 260 m thick along section A-A'

Kir **Rollins Sandstone Member**—Yellowish-gray to very pale-orange, fine-grained, well sorted sandstone. Beds are commonly massive to thinly bedded containing partings of siltstone and mudstone. Clasts in map unit consist of 70% quartz, 20% feldspar, <10% rock fragments and dark mafic minerals, and a trace of muscovite. Rollins Sandstone Member is in part equivalent to the Trout Creek Sandstone Member of Madden (1989), but because Madden miscorrelated the Trout Creek at Harvey Gap, 6 km to the west-northwest in the adjacent Silt quadrangle, the Rollins Sandstone nomenclature is retained. The Rollins Sandstone Member ranges from about 20-40 m thick.

Kicc **Cozzette Sandstone and Corcoran Sandstone Members undivided**—Two sandstone intervals separated by a marine shale interval. The upper sandstone, the Cozzette Sandstone Member, is very pale orange to yellowish gray, well sorted, very fine grained, contains minor beds of medium-dark-gray shale and is about 15 m thick in the eastern part of the map area and 25 m thick in the western. Clasts in the sandstone consist of about 80% quartz, 15% feldspar, 5% dark rock fragments and mafic minerals, and a trace of muscovite. The Cozzette Sandstone Member has thinly laminated, flaggy bedding at the top and thicker bedding toward the base. The monotonous sequence of underlying marine shale is medium dark gray to dark gray and is about 30 m thick in both the eastern and western parts of the map area. The lower sandstone, the Corcoran Sandstone Member, is light brownish gray to yellowish gray, moderately sorted, fine- to very fine-grained, contains minor interbeds of medium-gray shale, is about 45 m thick in the eastern part of the map area and 65 m thick in the western, and has clasts that consist of about 75% quartz, 15% feldspar, 10% dark rock fragments and mafic minerals, and <1% muscovite which is concentrated along partings. Carbonaceous films are also present on partings. Thickness of the entire map unit is about 90 m in the eastern part of the map area and about 120 m in the western part

Kmvb **Baked zone in the Mesaverde Group**—Light-red, pale-red, and moderate-reddish-orange baked zone on either side of a clinker resulting from both historic and prehistoric burning of coal. This unit is kept in this part of the stratigraphic sequence because the protolith which was baked is Upper Cretaceous. The actual clinker zones of burnt coal are relatively thin, easily eroded light-gray ashy zones that are difficult to locate accurately in talus-covered slopes. Zone includes exposures of baked shales, siltstones, and sandstones, areas where thin colluvium from the baked zones has covered exposures with red debris, and the clinker zone. Some of the shale melted during the burns; this resulted in an unusual form of igneous rock that commonly has a brownish-gray to light-medium-gray aphanitic groundmass containing vesicles and inclusions of quartz that originally were pebbles of quartz that did not melt. The Grand Hogback is presently burning at two localities in the map area. One is located about 4 km south of the northern border of the map area and 3 km east of the western border on the northeast-facing slope of the hogback. The other is located about 0.4 km west of the largest building (school) on the west side of New Castle, also on the northeast-facing slope. No measurements of thicknesses of baked zones in the Mesa Verde Group were made

Mancos Shale (Upper Cretaceous to Lower Cretaceous)—The formation includes the upper member (Kmu), Niobrara Member (Kmn), Juana Lopez Member (Kmj), lower member (Kml), and the Juana Lopez and lower members undivided (Kmjl). The formation is about 1,540 m thick

Kmu **Upper member (Upper Cretaceous)**—Medium-dark-gray to dark-gray fissile shale that weathers light gray. Dark-gray to dark-yellowish-orange concretions typically 10 cm in diameter are common in the upper part of the unit, and dark-gray concretions about 30 cm in diameter are common in the lower part of the unit. Very pale orange, fine-grained sandstone forms beds 0.2-2.5 m thick near the top of the map unit. The middle part of the unit is predominantly a monotonous sequence of fissile, dark-gray shale, broken only by several 1-15-cm-thick dark-yellowish-orange bentonitic montmorillonite-rich beds. Near the lower contact with the Niobara Member (Kmn), calcareous shale is abundant in the upper member. Exposures in the map unit are generally poor except where active stream erosion or roadcuts create fresh exposures. Landslide deposits (Qls) and debris flow deposits (Qd) coalesce to form a thick mantle of colluvial deposits (Qc) that cover much of the upper member of the Mancos near the northwest corner of the map area. Because the shale commonly contains expansive clays, the upper member locally may have high shrink-swell potential. This geologic hazard is exacerbated where the strata dip more than 30^{o} because expansive-clay-rich beds may expand upward more than adjacent beds less rich in expansive clays, causing differential heaving of foundations and other structures. Noe and Dodson (1995) and Noe (1996) describe the hazard of steeply dipping Pierre Shale along the Front Range in the Colorado Piedmont; however, the Mancos Shale may have fewer beds rich in expansive-clays than the Pierre Shale, found at least 50 km east of the map area. Gypsum occurs locally between shaley partings, and Na^{+}- and Cl^{-}-rich connate water is present in the shale of the upper member; these may create local chemical conditions damaging to untreated concrete and uncoated steel. The thickness of the upper member is about 1,280 m

Kmn **Niobrara Member (Upper Cretaceous)**—Light-gray- to very light-gray- weathering, fissile calcareous shale and blocky shaley limestone that commonly contains pearly fossils of pelecypods (*Inoceramus*). The change from medium-gray- weathering shale of the upper member (Kmu) to the light-gray rocks of the Niobrara member is gradational, and the contact is located at the most conspicuous color change from the darker gray of the upper member (Kmu) to the lighter gray of the Niobrara Member. In contrast, the lower contact of the Niobrara is placed at the base of the lowest limestone bed above the dark shale of the Juana Lopez Member (Kmj) or of the Juana Lopez Member and lower member, undivided (Kmjl). More limestone-rich intervals (2-5 m thick) are interbedded with more shale-rich intervals (3-6 m thick); beds are commonly less than 1 m thick in the upper part but are commonly 1 m thick at the bottom of the member. Excellent exposures of the unit occur on either side of the road along Elk Creek. The Niobrara Member is about 75-85 m thick

Kmj **Juana Lopez Member (Upper Cretaceous)**—Dark-gray fissile shale interbedded with intervals of medium-gray to light-olive-gray, weathering to pale-yellowish-brown to dusky-yellow, medium- to thin-bedded and laminated calcareous siltstone and sandstone characterized by fragments of brownish-black pelecypod fossils (Merewether and Cobban, 1986; Molenaar and Cobban, 1991). Excellent exposures of the unit occur on the northeast side of the road along Elk Creek. Base of the Juana Lopez Member is defined by the lowest sandstone above the monotonous sequence of dark shales of the lower member (Kml) The Juana Lopez Member is about 35-40 m thick

Kml **Lower member (Lower Cretaceous)**—Monotonous sequence of pale-yellowish-brown weathering, dark-gray fissile shale. Toward the base of the map unit, thin interbeds of brownish-gray to light brownish-gray sandstone overlie a gradational contact with the Dakota Sandstone (Kd). Thickness of the lower member ranges from about 105-145 m

Kmjl **Juana Lopez and Lower Members undivided (Upper to Lower Cretaceous)**—Dark-gray fissile shale and interbeds of sandstone and siltstone. Undivided where poor exposures prohibit mapping individual members. Undivided map unit ranges from about 140-185 m thick

Kd **Dakota Sandstone (Lower Cretaceous)**—Very pale-orange to very light-gray, medium-grained, well sorted quartz sandstone. Unit forms a prominent narrow hogback because a strong siliceous cement makes the Dakota the most resistant unit in the map area. In many localities the base of the unit is characterized by granules and pebbles of chert and quartzite < 2 cm in diameter. Although beds are planar in the upper part of the unit, crossbedding is common toward the base. Where the sandstone dips greater than about 30°, the unit is not prone to landslides, but where the dip is less than about 20°, landslides are common, for example, 2 km east of the northwest corner of the map area. Where landslides (Qls) occur at this stratigraphic level, both the overlying Mancos Shale (Km) and the underlying Morrison Formation (Jm) are involved in sliding. Good exposures of the Dakota occur where East Elk and Main Elk Creeks cut the Dakota hogback. The base of the Dakota Sandstone is in sharp unconformable contact with the underlying Morrison Formation. Thickness of the map unit is about 40-55 m

Jm **Morrison Formation (Upper Jurassic)**—Light-greenish-gray to dark-greenish-gray and pale-red-purple to grayish-red-purple siltstone and claystone interbedded with intervals of very light-gray to medium-gray, medium- to fine-grained sandstone. Locally, pebble and granule conglomerate occurs, and light-gray to medium-light-gray limestone beds are present in the lower part of the unit. At the Teakee uranium mine, 2.9 km east of the northwest corner of the map area, the sandstone contains dark organic partings and bright yellow deposits of carnotite on fracture surfaces. The base of the Morrison Formation makes a sharp contact with the underlying Entrada Sandstone. The Morrison Formation may locally contain expansive clays and locally have high shrink-swell potential (Noe, 1995). Thickness of the map unit is about 140-180 m

Je **Entrada Sandstone (Upper Jurassic)**—Grayish-orange-pink to very light-gray, fine- to very fine-grained, well sorted, friable, calcareously cemented quartz sandstone. Large-scale, steep crossbedding is common. Rock weathers to smooth, rounded exposures that commonly form small cliffs at the base. The base of the unit forms a sharp unconformable contact with the underlying Chinle Formation (dc). Thickness of the map unit is about 25-35 m

dc **Chinle Formation (Upper Triassic)**—Moderate-red, moderate-reddish-orange, and pale-red-purple siltstone and calcareous siltstone. These siltstones probably belong to the red siltstone member (Stewart and others, 1972b). Contact with underlying State Bridge Formation is difficult to locate because the mottled member and Gartra members present in the South Canyon Creek valley in the adjacent Storm King Mountain quadrangle (Stewart and others, 1972b) east of the New Castle quadrangle were not recognized in the New Castle quadrangle. The contact in the New Castle quadrangle is based on a subtle color change, typically from moderate reddish orange of the Chinle Formation to moderate red and grayish red of the State Bridge Formation (dPs). Thickness of the Chinle Formation is about 110-130 m

dPs **State Bridge Formation (Lower Triassic? and Permian)**—Three members (upper member, South Canyon Creek Member, and lower member) were mapped undivided, but the South Canyon Creek Member is shown as a dashed line separating the upper and lower members. Thickness of the formation is about 40-80 m

Upper member—Moderate-red, dusky-red, pale-red, and grayish-red siltstone and silty claystone interbedded with minor beds of pale-red and grayish-pink to grayish-red and beds of light-olive-gray and greenish-gray to light-greenish-gray, fine-grained, mottled sandstone. Thickness of the member is about 25-50 m

South Canyon Creek Member—Light-gray to very light-gray, fine-grained, dolomitic sandstone bed in the south part of the map area, grading laterally into pale-yellowish brown dolomitic sandstone with medium gray mottles in the central part, and grading into a very pale-orange fine-grained sandstone in the west part of the map area. Based on poorly preserved and sparse fauna, Bass and Northrop (1950) estimate that the age of this member is Permian. Redefined as a member of the Maroon Formation (Johnson and others, 1990). The South Canyon Creek Member is described in the measured section by Stewart and others (1972a) and is about 1-2 m thick throughout the map area

Lower member—Pale-red to grayish-red siltstone and fine-grained silty sandstone containing light-gray and light-olive to greenish-gray mottles. The lower member overlies the Schoolhouse Member of the Maroon Formation at a sharp contact. Member is about 10-25 m thick

Phm **Maroon Formation (Permian and Pennsylvanian)**—Formation symbol (Phm) shown in cross section only. The formation contains four members that are shown on the map, the Schoolhouse Member (Phms), middle member (Phmm), white sandstone member (Phmw), and lower member (Phml). Formation is about 1,000-1,300 m thick

Phms **Schoolhouse Member**—Very light-gray to medium-dark-gray, yellowish-gray, and pale red, very fine-grained to very coarse-grained, calcareously cemented sandstone and sparse pebble and cobble conglomerate. Minor pale-red to light-greenish-gray siltstones and minor mudstones occur between some sandstone beds. Crossbedding and channels are common. Clasts in the sandstone include about 50% quartz, 35% feldspars, 15% rock fragments and dark mafic minerals, and traces of muscovite and biotite. Clasts in the conglomerate include quartz, feldspar, felsic and mafic metamorphic rocks, quartzite, granitic rocks, and limestone as much as 12 cm in diameter. The unit was studied at South Canyon valley in the adjacent Storm King Mountain quadrangle to the east of the map area by Johnson and others (1990) and by Stewart and others (1972a). The map unit is about 60-100 m thick

Phmm **Middle member**—Pale-red, grayish-red, light-red, and grayish-pink, calcareous, fine- to coarse-grained, micaceous sandstone and pebble and cobble conglomerate interbedded with moderate red and grayish-red calcareous siltstone and mudstone. Conglomerate is more common in the upper part of the member. Sandstones, siltstones, and mudstones contain mottles where the red oxidized iron colors have been reduced to light greenish gray and very light gray. Crossbedding and channels are common. Clasts in the sandstone include about 40% quartz, 45% feldspars, 14% rock fragments and dark mafic minerals, and 1% of muscovite. Clasts in the conglomerate include quartz, feldspar, felsic and mafic metamorphic rocks, and granitic rocks as much as 8 cm in diameter. Thickness of the map unit is about 800 m

Phmw **White sandstone member**—Yellowish-gray, pinkish-gray, pale-pink, and very light-gray, fine- to coarse-grained, crossbedded, calcareous sandstone interbedded with minor pale-red to light-greenish-gray siltstone; conglomerate is sparse. Member can be traced across the entire map area and is about 70-75 m thick

Phml **Lower member**—Pale-pink to light-gray, pale-red, pale-reddish-brown, and grayish-red fine- to coarse-grained, calcareous and highly micaceous sandstone, siltstone and mudstone interbedded with at least two unmapped light-gray to medium-light-gray, nonfossiliferous limestone and silty limestone beds 1-4 m thick. Contact with the underlying Eagle Valley Formation is gradational and is located at the base of lowest sequence of widely existing pale-red to grayish-red sandstone beds. The lower member is about 190-200 m thick

hev **Eagle Valley Formation (Middle Pennsylvanian)**—Yellowish-gray, very pale-orange, light-olive-gray, greenish-gray to light greenish-gray, light-gray, dark-greenish-gray, and sparse pale-red calcareous, fine- to coarse-grained, micaceous sandstone, siltstone, and mudstone interbedded with two major highly fossiliferous limestone beds (hel, described below). Sparse beds of gypsum and anhydrite of the Eagle Valley Evaporite (hee, described below) within the Eagle Valley Formation are largely covered with unmapped colluvium; at these localities, the presence of gypsum, anhydrite, and possible halite can cause damage to untreated concrete and uncoated steel. Bedding is parallel to subparallel and contains few crossbeds and channels. The base of the map unit is faulted out in the northeastern corner of the map area. Bass and Northrop (1963) reported that in the upper 120 m of the formation fossiliferous limestone beds (hel) contain Desmoinsian age (Middle Pennsylvanian) fossils. The best exposures of the map unit are along the stream valley that trends northeast toward the northeast corner of the map area. About 1,000 m of the map unit is exposed in the map area

hel **Limestone beds**—Dark-gray to medium gray, weathering to light-brownish-gray limestone beds; minor limestone beds are present but are not mapped. The upper and lower limestone beds are about 40 and 20 m thick, respectively, where they are well exposed in the stream valley that trends northeast toward the northeast corner of the map area

hee **Eagle Valley Evaporite**—White to medium-gray and brownish-gray laminated gypsum anhydrite and possibly halite. There is only one good exposure of the evaporite; it occurs in the northeastern part of the map area. About 3 kilometers to the north in the Deep Creek Point quadrangle, thick masses of Eagle Valley Evaporite are exposed in extrusive contacts with the Maroon Formation (Phm) and the Eagle Valley Formation (hev); similar structural relations are present in the northern part of the Storm King Mountain quadrangle (Bryant and others, 1998). Evaporite minerals in the unit can damage untreated concrete and uncoated steel. The one exposure in the map area is about 40 m thick

STRATIGRAPHY

Members of the Wasatch Formation were mapped following the stratigraphic framework provided by Donnell (1969) which describes Wasatch units exposed south of Rifle Gap 12 km west-northwest of the New Castle quadrangle along the Grand Hogback. At that locality, Donnell recognized equivalents of the Shire, Molina, and Atwell Gulch Members. Unpublished mapping in the Silt quadrangle west of the New Castle quadrangle and mapping in the Rifle quadrangle (Shroba and Scott, 1997) physically confirm the correlation from Rifle Gap to the New Castle area. Both the Molina and the Atwell Gulch Members thicken significantly toward the southeast from Rifle Gap where Donnell measured them at 105 m and 170 m thick, respectively. In the New Castle quadrangle the Molina is 210-280 m and the Atwell Gulch is 240-400 m thick. Higher stratigraphically in the Wasatch Formation, a sandstone unit (Twss) that is lithologically similar to the sandstone intervals that characterize the Molina Member occurs about 500 m above the Molina in the New Castle area. This sandstone unit forms a 60-80-m-thick interval within the Shire Member. The mudstone-rich interval of the Shire Member between the overlying sandstone unit (Twss) and the underlying Molina Member thins from 500 m in the New Castle quadrangle to about 100 m on the western side of the Silt quadrangle.

The terminology of Warner (1964) is used in this report for the lower part of the Mesaverde Group, particularly for the Rollins Sandstone (equivalent to the Trout Creek Sandstone Member in northwestern Colorado), the Cozzette Sandstone, and the Corcoran Sandstone Members of the Iles Formation. Although these three sandstone members can be physically mapped from the Rifle quadrangle at Rifle Gap southeastward through the New Castle quadrangle, map relations are not as obvious in the Storm King Mountain quadrangle to the east. Bryant and others (1998) could not map a continuous interval of the Rollins Sandstone Member (which they called the Trout Creek), either because of limited exposure or local absence of the unit, or both. This sandstone unit was mapped as the Rollins Sandstone Member of the Williams Fork Formation in the Cattle Creek quadrangle southeast of the Storm King Mountain quadrangle (Kirkham and others, 1996). The Cozzette and Corcoran Sandstone Members were mapped as a combined unit, as they were in the Storm King Mountain quadrangle by Bryant others (1997).

In this report, the terminology for sandstone and shale units below the Niobrara Member of the Mancos Shale and above the Dakota Sandstone is taken from Merewether and Cobban (1986) and Molenaar and Cobban (1991). Therefore, the upper unit, the calcareous sandstone and dark shale unit, is termed the Jauna Lopez Member and the underlying dark shale is termed the lower member of the Mancos Shale. Bryant and others (1998) also follow this terminology in the Storm King Mountain quadrangle.

Rocks that are transitional between the arkosic Maroon Formation and the Eagle Valley Evaporite are called the Eagle Valley Formation is this report, following the usage of Bryant and others (1998). The Eagle Valley Formation is finer-grained, is more evenly and thinly bedded, and has colors with more brown and yellow than the overlying Maroon Formation. Also, the Eagle Valley Formation contains more clastic rocks and fewer evaporites than the underlying Eagle Valley Evaporite.

STRUCTURE

The New Castle quadrangle extends from the southwestern flank of the White River uplift, across the Grand Hogback monocline, to the southeastern part of the Piceance basin. In the southwestern part of the map area, the Wasatch Formation dips less than 7^o and shows no evidence of deformation related to the Divide Creek Anticline that ends about 8 km south of the map area (Gunneson and others, 1995). From the southwestern corner of the map area toward the northwest, the unfaulted early Eocene to Wasatch Formation and underlying Mesaverde Group gradually increase in dip to form the Grand Hogback monocline that reaches 40-50^o dips to the southwest (section A-A’). In contrast to this relatively simple structure, northeast of the valley carved into the Mancos Shale by Elk Creek and the Colorado River, a 6-km-long lobe of Lower Cretaceous through Permian strata lies about 1 km southwest of the primary trend of the Dakota Sandstone hogback. The northwestern end of this lobe ends where noses of an anticline-syncline pair plunge shallowly toward the west (section B-B’). The northeastern margin of this lobe consists of a southwest-dipping thrust fault separating shallowly dipping Maroon Formation in the lobe from a steeply dipping panel (section A-A’). Toward the southeast this thrust fault splays into three thrust faults forming the southeastern end of the lobe. The geometry of these minor thrusts shown in section A-A’ requires an explanation. All three are interpreted to place older rocks over younger rocks associated with folds presumably generated during compression, not extension. However, the apparent transport direction of the hanging wall is downward, similar to the geometry of normal faults. We resolve this apparent inconsistency by suggesting that these thrusts occurred earlier in the sequence of Laramide deformation, prior to the major uplift and tilting that produced the Grand Hogback monocline. Rotation of this part of section A-A’ to stratal attitudes close to horizontal produces a consistent thrust geometry. These thrusts were then rotated during the last phase of Laramide deformation and uplift of the White River Plateau to their present attitudes with a southwest dip. Because there is not a significant angular unconformity at the base of the early Eocene and Paleocene Wasatch Formation and because the upper part of the Wasatch Formation has been deformed by the uplift, this last phase of Laramide deformation must have persisted at least until early Eocene (Tweto, 1975).

The minor thrust shown to dip southwestward from the upper part of the subsurface at the northeast end of section B-B’ is a northwestern projection of part of the same thrust system splays exposed in section A-A’. Also a minor east-west trending high-angle reverse fault cuts the Dakota Sandstone ridge between East and Main Elk Creeks; the relation of this fault to other structures is unclear.

East and northeast of these three thrust faults, a steeply southwest-dipping panel starting with the lower part of the Mancos Shale and Dakota Sandstone progressively dips more steeply down section, becomes overturned in the Maroon Formation and the Eagle Valley Formation, and reaches overturned dips as low as 55^o to the northeast in the deep valley that nearly intersects the northeastern corner of the quadrangle. Ridge tops on either side of the valley, however, are right-side up; limestone beds (hel) in the Eagle Valley Formation form a gentle to sharp fold as they are traced from overturned beds in the valley to right-side-up beds on the ridges. A down faulted, northeast-dipping right-side-up sequence of the Maroon Formation forms the northeasternmost corner of the map area.

A genetic interpretation of the fault, stratal attitudes, and fold geometry in the strata below the Mancos Shale requires a more regional tectonic interpretation of Laramide deformation. Unpublished seismic lines in the Glenwood Springs area 16 km to the east that extend southwestward from the southern flank of the White River uplift under the Grand Hogback into the Piceance basin show a low-angle blind thrust that placed a high-velocity Precambrian basement hanging wall over a low- velocity Eagle Valley Evaporite footwall by a few kilometers, similar to that shown in section B-B’. The blind thrust dips under the uplift with westward (basinward) transport direction. Presumably that blind thrust is a northward subthrust extension of the West Elk thrust, which is well exposed in the Redstone-Marble area (about 50 km south of Glenwood Springs) (Tweto and others, 1978). Given this geometry it is reasonable to assume that the White River uplift and the Grand Hogback are largely a result of blind thrusting that creates a wedge of basement and an associated triangle zone structure at the foreland margin (Jones, 1987, fig. 17; Erslev, 1993a, fig. 4; Erslev and Rogers, 1993b, fig. 14).

Unpublished drill-hole data provide a geometry that is compatible with this blind-thrust interpretation of the White River uplift and the Grand Hogback as shown in section B-B'. In that section, the series of interpreted low-angle overthrusts between about 0.5 and 2 km below sea level theoretically would be minor splays of a major overthrust hypothetically shown at about 3.5-4 km depths. Presumably the siltstone in the Maroon Formation and evaporite in the Eagle Valley Evaporite absorb the strain suggested in the zone of minor overthrusts. The geometry below the top of the Eagle Valley Evaporite assumes that the nearly 1,500 m of evaporite (De Voto and others, 1986) and about 400 m of Mississippian and older Paleozoic rocks are present above the nose of the wedge of Precambrian basement (Campbell, 1972).

GEOLOGIC HAZARDS

Geologic hazards in the map area include erosion, expansive soils, corrosive minerals, and flooding. Erosion includes mass wasting, gullying, and piping. Mass wasting involves any rock or surficial material that moves downslope under the influence of gravity, such as landslides, debris flows, or rock falls and is generally more prevalent on steeper slopes. Gullying and piping generally occur on more gentle slopes. Expansive soils and expansive bedrock are those unconsolidated materials or rocks that swell when wet and shrink when dry. Soluble minerals such as gypsum and halite in evaporitic bedrock units become corrosive to untreated concrete and metal when these minerals dissolve in water. Most floods are restricted to low-lying areas. Table 3 summarizes the geologic hazards that are prone to occur on or in geologic units in the map area.

Table 3. Geologic hazards and related map units in the New Castle quadrangle.

EROSION					VOLUME CHANGE		CORROSIVE MINERALS	FLOODING	
mass wasting			gullying	piping	hydro-compaction	expansive materials			
Qls	Qc	Qd	Qac	Qac	Qc	Kmu	hee	Qfp	Qfy
Qac		Qfy	Qlo	Qlo	Qls	Jm	hev	Qd	Qac
Tws	Twss	Twm			Qlo	Qfy	Kmu	Qsw	
Twav	Twal	Kwf				Qac	Qls		
Kwfu	Kwfl	Ki				Qls	Qc		
Kir	Kicc	Kmu				Qc			
Kmn	Kmjl	Kmj				Qd			
Kml	Kd	Jm							
Phm	Phms	Phmm							
Phmw	Phml	hev							

Where rock units and surficial units in the New Castle quadrangle occur on steep slopes mass wasting is common. Most of these rock units that are prone to mass wasting have low shear strength, either because they are clay rich or because they have planes of weakness parallel to bedding planes or jointing. As a result, landslides and creep are common. The term “landslide”, as used in this report, includes several mechanisms of rapid to slow mass transport of surficial and bedrock material downslope. These mechanisms (Varnes, 1978) commonly produce debris-slide, rock-slide, debris-slump, rock-slump, slump-earth-flow, earth-flow, and debris-flow deposits in the map area. These deposits are indicated on the map by their map unit symbols Qls (landslide deposits), Qd (debris-flow deposits), and Qc (colluvium, undivided). These deposits are mapped both by observed geomorphic features on aerial photography and by field observations of their distinctive hummocky topography, deflection of stream channels at the toes of deposits, their headwall scarps, lobate form of the deposits, differences in vegetation on these deposits compared to adjacent stable areas, anomalous strike-and-dip attitudes of bedrock, and material found downslope from their sources. The map unit Qc locally includes old coalesced landslide and debris-flow deposits that are no longer mappable as separate units because their geomorphic expression has been obliterated by erosion.

Landslide and debris-flow deposits are commonly derived from shale- or mudstone-rich units in the stratigraphic sequence, specifically (1) the Wasatch Formation (Tw), (2) the upper member of the Mancos Shale (Kmu) and the lower part of the overlying Iles Formation (Ki), (3) the lower member of the Mancos Shale (Kml), the Dakota Sandstone (Kd), and the Morrison Formation (Jm), (4) the Maroon Formation (Phm) and the underlying Eagle Valley Formation (hev), and (5) surficial deposits (Qac, Qls, Qc, Qd, and Qfy) derived from these bedrock units.

The Wasatch Formation south of the Colorado River exhibits numerous landslide and debris-flow deposits, commonly on steep slopes. Landslides are particularly abundant on either side of the high geomorphic surface on unit QTab between Garfield Creek and Divide Creek. This surface is decorated by several headwall scarps on its north and eastern sides above landslide deposits. A large rock slump, 2 km north of the southern boundary and 4 km east of the western boundary, is essentially intact and is over 2 km long.

Although the southwestern dip slope of the Grand Hogback is free of landslides, the northeastern side has abundant landslides and debris flows. Large areas of colluvium (Qc) on the northeast side of the hogback form a thick apron of old landslide and debris-flow deposits, derived from the lower part of the Iles Formation (Ki) and the upper part of the upper member of the Mancos Shale (Kmu), that almost completely covers the Mancos. Sites for future homes and other human-made structures on this side of the Grand Hogback should be carefully evaluated for the potential of landslides and debris flows. Also, unmapped rock-fall deposits are common downslope from sandstone ledges in the Iles Formation (Ki) and the Williams Fork (Kwf) Formations on the northeast side of the Grand Hogback, particularly below Coal Ridge on the south side of the Colorado River.

About 2.5 km east of the northwestern corner of the map area, a landslide deposit about 500 m square was derived from the lower member of the Mancos Shale (Kml), the underlying Dakota Sandstone (Kd), and the uppermost part of the Morrison Formation (Jm). Although toward the southeast few landslide deposits were derived from this part of the stratigraphic sequence where these units dip from 40^{o} to 60^{o}; this slide occurred on a dip slope with attitudes of about 10^{o}-15^{o}. This relationship between a low-angle dipslope and landslides is unclear, but lower slopes may increase precipitation infiltration relative to runoff, thus promoting slope instability. In the Wolcott quadrangle about 75 km to the east, Lidke (1997) reported landslides at the same bedrock interval on a dipslope of similar low bedrock dips. Natural and human-induced factors that affect slope stability, such as increased pore pressure, reduction of lateral support, or removal of vegetation, could result in the reactivation of existing landslide deposits or in the activation of potentially unstable geologic areas.

The Maroon Formation is particularly prone to the formation of debris-flow deposits (Qd); there are good examples in the northeastern part of the quadrangle as well as in the adjacent Storm King Mountain quadrangle to the east (Bryant and others, 1998). Debris-flow deposits over 1 km long are present in the map area east of East Elk Creek. The source of these deposits is loose debris on the steeply dipping panels of sandstone in the Maroon Formation. Future debris flows may occur in this area and may pose a hazard to some of the houses built on existing debris-flow material. Recent events on and near Storm King Mountain indicate that forest fires followed by intense rainfall are especially conducive to the generation of large debris flows (Cannon and others, 1995).

In the northeastern part of the New Castle quadrangle, most of the Eagle Valley Formation is covered by unmapped colluvium of various thicknesses. Much of this colluvial debris consists of debris-flow and landslide deposits that could not be mapped because of dense vegetation. One large landslide deposit was mapped along the steeply dipping rocks near the northern boundary of the map area, and a fresh landslide scar is present in the smaller landslide deposit to the east.

Gullying commonly occurs in well sorted, poorly consolidated, silty and sandy alluvial, colluvial, and eolian deposits where runoff is concentrated, such as in the ruts formed in dirt roads. Gullying is more pronounced in undivided alluvium and colluvium (Qac) and in loess (Qlo). Piping was observed in undivided alluvium and colluvium and loess.

The upper member of the Mancos Shale (Kmu) locally contains bentonitic smectite-rich beds and is locally overlain by expansive soils. The Morrison Formation (Jm) may locally contain similar beds and locally may be overlain by expansive soils. These bentonitic units and soils can expand significantly when wet and shrink when dry; these properties tend to disrupt building foundations and other structures. Where strata containing different amounts of smectite are steeply dipping, as they are in the New Castle quadrangle, the detrimental effects are often more pronounced than if the strata were nearly horizontal because of uneven heaving of foundations and other structures (Noe, 1996; Noe and Dodson, 1995). Colluvial and some alluvial deposits derived from these units may also have expansive characteristics.

Several map units contain soluble minerals that, when dissolved in water, cause corrosion of untreated concrete and metal. These minerals include gypsum and halite in evaporite deposits in the Eagle Valley Evaporite (hee) and the Eagle Valley Formation (hev). The gypsum partings in the upper member of the Mancos Shale (Kmu) can also cause corrosion, and the connate water trapped in that shale contains significant concentrations of seawater that are also corrosive.

Flooding is generally restricted to low-lying young surficial units, but also occur on higher units such as younger alluvial-fan and debris-flow deposits (Qfy). Construction of permanent structures on flood plain and stream channel deposits (Qfp) should be avoided along the Colorado River and its tributaries such as Elk Creek west of the town of New Castle. Intense thunderstorms in the highlands north of New Castle have caused flash floods along the stream channel in undivided alluvium and colluvium (Qac) about 1.5 km north of the town. At the end of this stream channel, houses are being constructed on younger fan-alluvium and debris-flow deposits (Qfy) where stream flow periodically inundate and adds debris to the fan. The trailer court and housing development on the south side of the Colorado River at the mouth of Alkali Creek are prone to a similar hazard of flash flooding posed by Alkali Creek. A housing development in the north-central part of the map area is built on debris-flow deposits (Qd) on the east side of East Elk Creek, 3.5 km north of the confluence with Elk Creek; stream channels in these deposits have the potential to inundate parts of the housing development with flood waters and new debris flows generated by intense thunderstorms.

ENVIRONMENTAL ISSUES

Several environmental issues were recognized in the course of making the geologic map for the New Castle quadrangle. These issues include dissolution of Pennsylvanian evaporites and gypsum partings in the Mancos Shale, potential environmental problems related to past coal mining and related active burning of coal beds along the Grand Hogback, and possible environmental concerns regarding mine tailings at uranium mines in the Morrison Formation.

Gypsum and (or) halite dissolves from exposures of the Eagle Valley Formation (hev), the Eagle Valley Evaporite (hee), and the upper member of the Mancos Shale (Kmu) and from subsurface interaction of these units with non-saline ground water. This dissolution will increase the salinity of East Elk, Main Elk, West Elk, and Elk Creeks, particularly where these creeks cross large exposures of the Eagle Valley Evaporite in the adjacent Adams Lake, Deep Creek Point, and Rifle Falls quadrangles northeast, north, and northwest of the New Castle quadrangle, respectively, based on unpublished mapping (R.B. Scott) and the regional geologic map by Tweto and others (1978). The dissolved load from these creeks adds to the load carried by the Colorado River from the salt-collapse centers surrounding the towns of Eagle and Carbondale (Kirkham and others, 1997). The quantity of dissolved material contributed by these creeks needs to be determined, and the portion of the dissolved loads derived from natural sources needs to be distinguished from the portion derived from extensive agricultural irrigation of the valley of Elk Creek, which is underlain by the Mancos Shale.

Numerous coal mines were active during the latter part of the 19th century and the early part of the 20th century along the Grand Hogback. Although the environmental impact of many of these mines (adits, shafts, and pits shown on the map) has been moderated by on-going reclamation by the State of Colorado, Department of Natural Resources, scattered coal mine tailings are still common in the map area. Organic debris from these un-reclaimed mines is carried in stream flow in washes southwestward and northeastward off the hogback. Numerous baked zones in the Mesa Verde Group (Kmvb) adjacent to clinker zones are shown on the map. Coal beds in at least two localities above the Rollins Sandstone Member (Kir) along the hogback north of the Colorado River are still burning; one is 0.4 km west of the large school building on the west side of New Castle and the other is about 4 km south of the northern border of the map area and about 3 km east of the western border. Melted and fused shales are exposed at the sites of some of the extinct burns. Temperatures are estimated to have reached between 650^{o} and 1050^{o} C or more where melting occurred. Orifices in the burn areas continue to emit hot sulfurous fumes, carbon dioxide, and probably carbon monoxide.

In exposures of the Morrison Formation (Jm) that form a shallowly west plunging anticline and syncline pair about 3 km east of the western border of the map area near the northern border, numerous prospects and small mines were excavated during uranium mining in the middle of the 20th century. The tailings of largest mine, the Teakee Mine, contain the bright-yellow uranium mineral carnotite along partings and fractures in sandstone. The potential environmental issues associated with radioactive minerals needs to be investigated, particularly the possible presence of radon gas in homes and drinking water in areas underlain by the Morrison Formation.

GEOLOGIC RESOURCES

Geologic resources in the New Castle quadrangle include coal, gas and oil, and sand and gravel. Coal mining in the New Castle area began by 1888 and continued intermittently until 1918, but was plagued by a series of fires and explosions. The first reported fire in a coal bed above the Rollins Sandstone Member (Kir) in 1895 caused a major explosion in the Vulcan Mine (location not shown on map) 2.5 km west of the town of New Castle, killing 50 miners, and resulting in mine closure. A second mine on the edge of New Castle near the west side of Elk Creek caught fire resulting in more deaths in 1899; that coal bed still burns. By 1912, a new mine was opened close to the site of the Vulcan Mine, but in 1913 an explosion killed 37 miners, and a second explosion and fire killed 3 miners. Finally the mine was sealed and allowed to burn. Fishell (1979a, 1979b) provided a summary of this coal mining history. A series of mine pits and steeply inclined adits were excavated south of the Colorado River along the base of Coal Ridge above the Rollins Sandstone Member and also above the lower unnamed sandstone unit. These pits and adits were described in a report by Gale (1910). Two mines, one on each side of the Colorado River, are located much higher in the stratigraphic sequence and are about 1.5 and 2 km southwest of New Castle. About 1.2 km east of the western border a cluster of mines between the Rollins Sandstone Member and the upper unnamed sandstone units are variously referred to as the Doll Mines by Madden (1989) and the Atlas Mine and unnamed mines by the Colorado Department of Natural Resources at their mine reclamation sites. No active mines exist in the map area.

Petroleum in the form of gas and oil is being extracted from the sandstones of the Iles Formation, mostly from the Rollins Sandstone Member (Kir). Ten wells were drilled in the map area and well locations are shown on the map; south of the Colorado River, eight were drilled to depths between 2,107 and 2,789 m in the southeastern part of the Piceance Creek basin through the Wasatch Formation into the underlying Mesaverde Group. Of these, six produce gas, one produces oil, and one showed only a trace of gas. Two wildcat oil wells were drilled northeast of the Grand Hogback along Elk Creek; both were dry and both were drilled with the objective of penetrating the overthrust (shown in section B-B') and tapping into suspected traps in the Mississippian Leadville Limestone (not exposed at the surface). Drilling problems encountered in both holes prevented successful completion, even though one reached a depth of 5,313 m and the other reached 3,013 m.

Abundant sand and gravel in the New Castle quadrangle are present in the flood plain and stream channel deposits (Qfp) along the Colorado River. Less abundant and (or) lower quality deposits are present in other flood plain and stream channel deposits as well as in younger terrace alluvium (Qty), intermediate terrace alluvium (Qtm), and older terrace alluvium (Qto) along the Colorado River and its major tributaries. Coarse clastic material (pebbles and cobbles) in channels is commonly overlain by sandy and silty overbank deposits; these sandy and silty deposits are more common along tributaries than along the Colorado River where gravel dominates. Most of the pebbles and cobbles in deposits along the Colorado consist of granite, gneiss, quartzite, sandstone, and porphyry. Two deposits have already been mined, but other areas of abundant reserves exist under land primarily used for agriculture.

MAP SYMBOLS

Contact—Solid where definite, dashed on map where approximately located, dashed in cross section to show stratal attitudes at depth

Trace of beds in hev, Phml, Phmm, trace of South Canyon Creek Member of dPs, and trace of coal beds in Kwf

Landslide scarp—Hachures on the landslide side of the scarp

Thrust fault—Sawteeth on upper plate of fault. Dashed where approximately located; dotted where concealed. Although these faults now have the geometry of normal faults, prior to tilting of the strata, the faults would have had the geometry of ramping thrusts

High-angle reverse fault, showing dip (barbed arrow) and trend and plunge of lineation (diamond-shaped arrow)—Solid rectangles on upthrown side of fault. Dashed where approximately located; dotted where concealed

Normal fault—Dashed where approximately located; dotted where concealed. Bar and ball on downthrown side

Syncline axial trace—Dotted where concealed. Solid arrows show direction of plunge of the axes

Anticline axial trace— dotted where concealed. Solid arrows show direction of plunge of the axes

Strike and dip of beds

Inclined

Horizontal

Overturned

Gas well— showing name of drilling company and total depth (TD) in feet

Dry hole— showing name of drilling company and total depth (TD) in feet

Mine shaft
Adit
Mine pit
F215 **Fossil locality**

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